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The role of biomass in the B.C. pulp and paper industry energy strategy : 1974 - 1984

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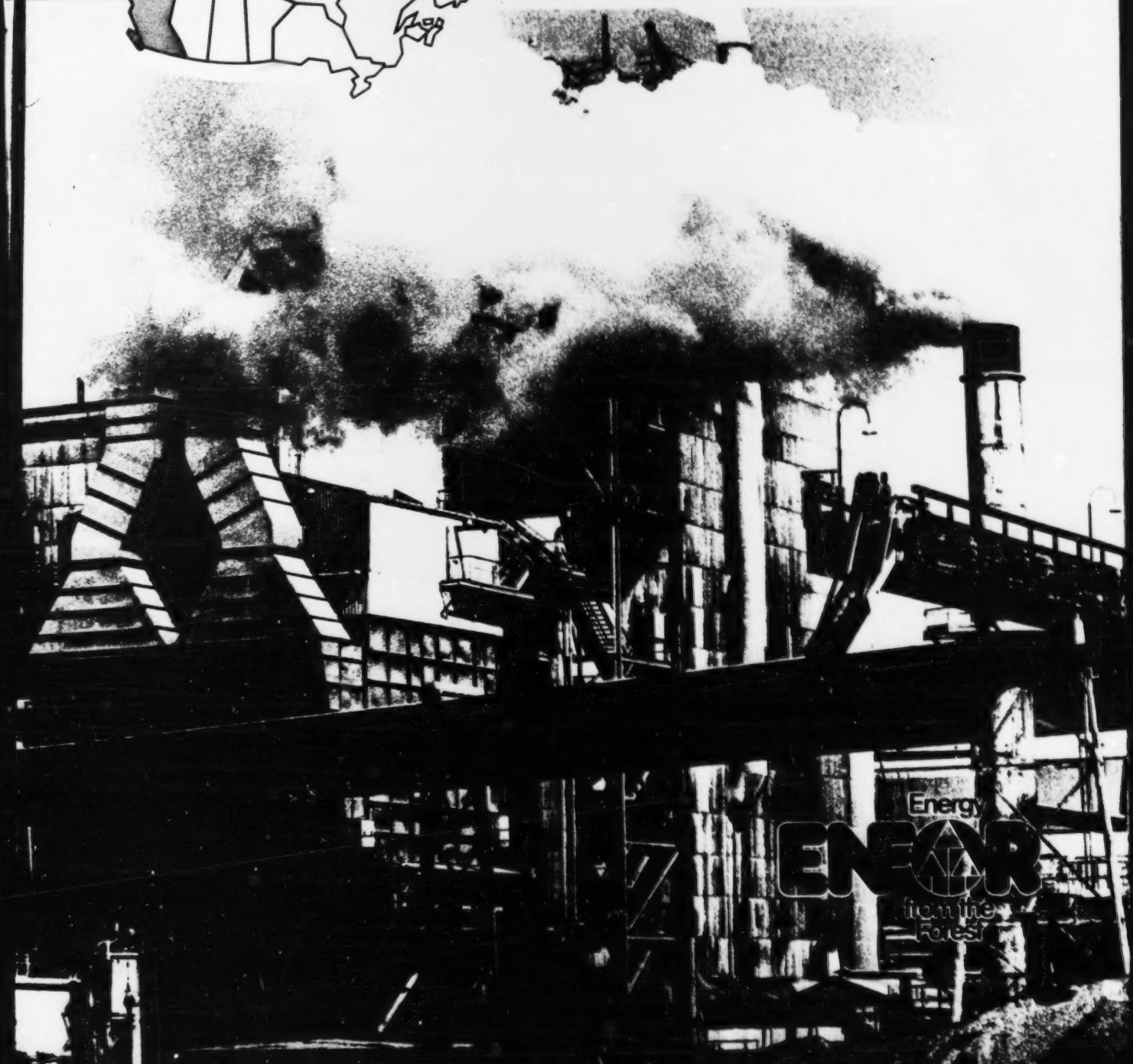

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The role of biomass in the B.C. pulp and paper industry energy strategy: 1974-1984

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Foreword

ENFOR is the acronym for the Canadian Government's ENergy form the FORest (ENergie de la FORêt) program of research and development aimed at securing the knowledge and technical competence to facilitate in the medium to long term a greatly increased contribution from forest biomass to our nation's primary energy production. This program is part of a much larger federal government initiative to promote the development and use of renewable energy as a means of reducing dependence on petroleum and other non-renewable energy sources.

The Canadian Forestry Service (CFS) administers the ENFOR Biomass Production program component which deals with such forest-oriented subjects as inventory, harvesting technology, silviculture and environmental impacts. (The other component, Biomass Conversion, deals with the technology of converting biomass to energy or fuels, and is administered by the Renewable Energy Branch of the Department of Energy, Mines and Resources). Most Biomass Production projects, although developed by CFS scientists in the light of ENFOR program objectives, are carried out under contract by forestry consultants and research specialists. Contractors are selected in accordance with science procurement tendering procedures of the Department of Supply and Services. For further information on the ENFOR Biomass Production program, contact...

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Abstract

The British Columbia pulp and paper industry dramatically altered its energy consumption patterns over the period 1974 to 1984. Sixteen mills, comprising 80% of the provincial pulp and paper capacity, participated in this study. Their responses suggest an annual fossil fuel saving equivalent to about 3.5 million barrels of oil has been achieved since 1974. The savings were achieved by replacing energy-inefficient equipment, implementing process changes, and increasing hog fuel consumption. However the responses also reveal a great variation among mills as each implemented the mix of energy projects best suited to its particular needs.

There is continuing pressure at most mills to further reduce fossil fuel consumption. Increased hog fuel consumption has played and will continue to play an important role in the effort of the pulp and paper industry to reduce fuel consumption.

Résumé

L'industrie des pâtes et papiers de la Colombie-Britannique a modifié de façon considérable sa consommation d'énergie au cours de la période de 1974 à 1984. Seize usines, représentant 80 % de la capacité de production de pâtes et papiers de la province, ont participé à l'étude. Les réponses qu'elles ont fournies indiquent une économie annuelle en combustibles fossiles équivalant à environ 3,5 millions de barils de pétrole depuis 1974. Ces économies ont été obtenues par le remplacement du matériel à forte consommation d'énergie, des modifications de procédés et l'accroissement de l'utilisation de déchets de bois comme combustibles. Toutefois, les réponses révèlent également beaucoup de différences entre les usines en ce qui concerne la combinaison des solutions adoptées par chacune pour répondre à ses besoins particuliers.

La pression de réduire davantage la consommation de combustibles fossiles existe toujours par la plupart des usines. L'accroissement de la consommation des déchets de bois comme combustibles a joué et continuera de jouer un rôle important dans l'effort de l'industrie des pâtes et papiers pour réduire sa consommation de combustibles fossiles.

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Introduction

The Canadian pulp and paper industry has significantly reduced its purchased energy consumption in response to the rapid and unpredictable rise in energy prices in the 1970s. The industry made a commitment in 1976 to reduce purchased fossil fuel consumption 12% by 1980 relative to the 1972 base year level. The industry surpassed this goal, achieving a reduction of 17.2%. The energy saving is equivalent to 3.5 million barrels of oil annually, in spite of an 18% increase in production (Hohol 1982). The industry made a further commitment to reduce purchased fuel consumption 30% by the end of 1984. It fell somewhat short of this target, but this goal is expected to be achieved by the end of 1985 (Canadian Pulp and Paper Association, personal communication).

The industry achieved the energy savings following a strategy that consists of two principal elements: firstly, to use less energy per unit of production by modifying processes (including machinery replacement, operational changes, and general housekeeping); second, to substitute biomass material, spent pulping liquors, and self-generated electricity for purchased fossil fuels. Between 1972 and 1984, fourteen new power boilers capable of converting wood wastes into steam have commenced operation in Canada.

At the mill level, the particular energy conservation strategy depends on the mill's characteristics and constraints: the age of the mill, the production process, the product lines, relative energy prices, cost and access to biomass, mill site constraints, and the management philosophy. The purchased energy reductions demonstrate the industry's success in conserving energy, but the industry must be examined on a mill by mill basis to understand how the savings were achieved.

The pulp and paper industry in British Columbia has also achieved substantial energy reductions. Results of this study indicate purchased fossil fuels per tonne of production in 1984 have declined about 35% since 1974. During this period, the industry spent more than $400 million on investments specifically aimed at reducing energy costs.

The purpose of this study is to document how mills located in British Columbia reduced their purchased energy requirements since 1974. What strategies were adopted? What was the relative importance of biomass in the overall energy conservation strategy? Data were collected by mail-out questionnaire and follow up discussions. In the following pages the results of the survey are presented and analyzed. We gratefully acknowledge the participating mills' excellent cooperation.

Methods

In 1984 there were 21 pulp and paper mills operating in British Columbia. Twenty of these were in operation prior to 1974. In addition, the Quesnel River Pulp Mill commenced operations in 1982. This mill was not included in the study due to the lack of historic information. Along with the questionnaire, the mills were asked to confirm a statement of the mill's characteristics and major energy-related investments over the 1974/84 period. Of the 20 mills, 16 returned the completed questionnaire. Of the four mills that did not return a completed questionnaire, three were in the interior and one was on the coast. The participating mills accounted for 80% of the provincial pulp and paper capacity in 1984[1].

The mills' energy strategies were examined over the period 1974-1984. International crude oil prices rose substantially in two episodes during the 1970s. The first price shocks were in 1972 followed by a larger price rise in 1978/79. Because of the lead time necessary to plan and implement a capital investment, the industry did not adjust immediately to the energy crisis. We reasoned that by 1974 the mills would have started adjusting to higher fossil fuel prices and would have begun monitoring their energy consumption more closely. Hence, selection of 1974 as the initial year increased the likelihood of receiving complete and comparable data. Indeed, nearly every responding mill was able to fully answer the questionnarie. Information was also requested for the years 1978 and 1984. The year 1978 represents a midpoint in the study period as well as a year in which the industry was operating near capacity. The year 1984 was chosen to collect the most up-to-date information, although the indus-

[1] Throughout the remainder of the report, the 16 participating mills are referred to as the "industry."

try was generally operating at less than capacity.

The results are presented in aggregate (referred to as the industry) and separately for interior and coast mills. The information relating to the individual mills cannot be released since it was collected on a confidential basis.

The character of the industry differs significantly between the interior and the coast. Interior mills are generally newer, primarily produce market pulp, likely consume natural gas as their primary fossil fuel, and are subject to a continental climate. In contrast, nearly all of the coast mills were constructed before 1960, produce large volumes of paper products as well as market pulp, consume heavy fuel oil as their primary fossil fuel, and are located in a temperate maritime climate. The species of wood utilized by the interior and coast mills also differ. Given these differences, the industry's response to higher energy prices may differ between the two regions.

The questionnaire consisted of four general sections:

- energy consumption and price trends
- energy conservation measures
- fuel substitution
- ranking of energy investments.

The results are presented and discussed according to these four categories.

Results and discussion

Energy consumption and price trends

The mills were requested to estimate average energy consumption per tonne of product assuming full capacity production. This was the most workable method to normalize for changes in production capacity and product lines that occurred over the period. Consequently, differences in energy consumption among product lines (bleached or unbleached draft pulp, thermomechanical pulp, newsprint and paper) were not explicitly addressed in the questionnaire. Also, several mills provided actual energy consumption per tonne not normalized for full production, which may impart an upward bias to the average value reported by those mills. But, there

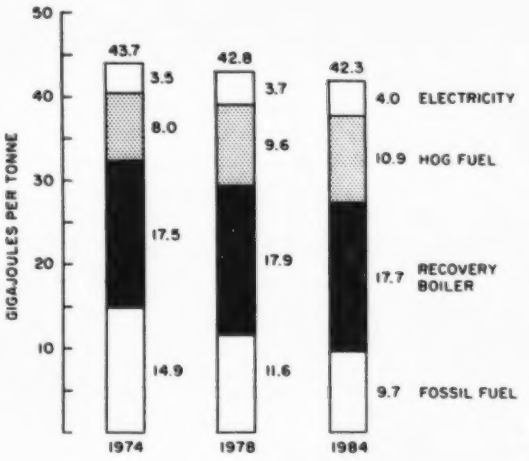

FIG. 1. Industry total energy consumption and fuel use

was no basis to adjust the data if the responding mill was unwilling to do so, hence it was included in the statistical analysis as reported.

The industry's average energy consumption per tonne of output for the three years is presented in Figure 1. In 1974, the industry total average energy requirement was 43.7 GJ/tonne. The responses indicated that total average energy consumption declined only slightly over the period to 42.3 GJ/tonne (i.e., a decline of 3.5%). As noted above, however, the 1984 estimate may be somewhat overstated due to those mills reporting actual consumption and operating at less than optimal production levels. In 1974, the range of average total energy consumption was 27 GJ/tonne for one coast mill to an industry high of 71 GJ/tonne at another coast mill. By 1984 the range had changed very little: 30 GJ/tonne to 69 GJ/tonne. Of the 14 mills that provided complete information on Question 1, six mills registered an increase, and eight mills indicated a decline in total average energy use. All but one of the responding interior mills were in the later category.

Although the data indicate little change in total energy requirements average fossil fuel consumption (heavy fuel oil and natural gas) fell 35% from 15 GJ/tonne in 1974 to 10 GJ/tonne in 1984 (Fig. 1). This savings is equivalent to about 3.5 million barrels of oil per annum relative to 1974 fuel use patterns and assuming the responding mills' 1984 capacity production levels. Given that total energy requirements changed little

over the period, fossil fuel savings appear to have been achieved primarily through interfuel substitution. Biomass (e.g., hog fuel) consumption increased from an average value of 8.0 GJ/tonne in 1974 to 10.9 GJ/tonne in 1984, a 36.7% increase. Average electricity consumption increased from 3.5 GJ/tonne in 1974 to 4.0 GJ/tonne in 1984, an increase of about 13%. The recovery boiler continued to be the largest single energy source within the average mill, but energy consumption remained essentially unchanged at about 18 GJ/tonne[2].

The corresponding energy data for the interior and coast mills (Tables 1 and 2) reveal some interesting features . First, the interior mills on average consume more energy per tonne of production. This gap narrowed over the period as the interior mills achieved a 14% reduction in average total energy consumption while the average requirement was essentially unchanged for coast mills. The average total energy value for coast mills was about 40 GJ/tonne. In most years, the coast mills producing both pulp and paper had an average value 15 to 20% below the aggregate coast value.

Secondly, in 1974 the average fossil fuel requirement of interior mills was 17.4 GJ/tonne compared to an average coast value of 14 GJ/tonne. The interior average value dropped in the 1974/78 period and continued to decline to an average value of 7.7 GJ/tonne in 1984. This is less than the average coast fossil fuel requirement in 1984 of 10.5 GJ/tonne.

Thirdly, interior mills obtain more of their total average energy requirements from the recovery boiler. The recovery boiler at the interior mills contributed about 23 GJ/tonne compared to a coast value of about 15 GJ/tonne.

Lastly, for interior mills, average fuel use increased for biomass only; the average requirement for electricity and energy from the recovery boiler remained nearly constant while fossil fuel use declined. Biomass consumption increased from 10.0 GJ/tonne in 1974 to 12.8 GJ/tonne in 1984. In contrast, for coast mills, consumption of

Table 1. Average energy consumption — Interior mills (GJ/tonne product)

	1974	1978	1984
Fossil fuels	17.4	8.9	7.7
Electricity	2.9	3.0	2.9
Hog fuel	10.0	12.4	12.8
Recovery boiler	23.2	23.2	22.9
Total energy*	53.5	47.5	46.3

Table 2. Average energy consumption — Coast mills (GJ/tonne product)

	1974	1978	1984
Fossil fuels	13.9	12.6	10.5
Electricity	3.8	4.0	4.4
Hog fuel	7.2	8.5	10.2
Recovery boiler	15.2	15.8	15.7
Total energy*	40.0	40.9	40.7

* Totals may not add due to rounding

biomass, electricity and energy from the recovery boiler all increased over the period. This suggests that the collective energy strategy of the interior mills has focused on reducing total energy consumption and to a lesser degree on fuel substitution. For coast mills, the response appears more complex. The reduction of total energy requirements appears to have played a less important role relative to fuel substitution strategies. The information presented in the following sections will elaborate on this apparent difference.

The second question identified the nominal fuel prices faced by the mills over the period. The trend in energy prices was common to nearly all mills. In 1974, the price of heavy fuel was less than $15 per barrel, the price of natural gas was less than $1.00 per mcf, electricity was less than 10 mills per kilowatt hour, and hog fuel was less than $5.00/m³ solid wood equivalent (swe). In 1978, the price of heavy fuel remained less than

[2] One interior mill does not require a steam plant, and so does not use hog fuel or operate a recovery boiler. So as not to bias the calculation of average values, this mill's response to question 1 was excluded.

$15 per barrel at most (heavy fuel oil-consuming) mills. The price of natural gas had roughly doubled from the 1974 price to the $1.75 to $2.00 per mcf range. Electricity prices had also increased with half of the industry paying more than 10 mills per kilowatt hour. The price of hog fuel showed some price increase, but nearly the entire industry continued to pay less than $5.00/m³. By 1984, the prices of all purchased fuels were higher. Nearly all the mills purchasing heavy fuel oil were paying in excess of $30 per barrel. All of the mills that consume natural gas were paying in excess of $2.75 per mcf and most were paying more than $3.50. The price of electricity in 1984 was in the 20 to 30 mill per kilowatt hour range at most coast mills and in excess of 30 mills per kilowatt hour in interior mills. In contrast, most of the mills reported the price of hog fuel to be little changed from its 1974 price. Four mills reported increased hog fuel prices over the period. Three of these were coast mills. In 1984, the price of hog fuel ranged from less than $5.00/m³ (swe) at 11 mills, to about $13/m³ (swe) at one coast mill.

The incentive to reduce purchased fuel consumption by reducing total energy consumption and substituting a lower cost fuel is clearly apparent. The incentive appears particularly compelling in the 1978/1984 period when fuel prices rose dramatically. In the next section, the industry's response in terms of reducing total energy consumption is addressed.

Energy conservation

Energy conservation was defined in the questionnaire as an investment/modification that reduced the energy input requirement per tonne of production. Under this general heading, three categories were identified: general housekeeping measures, machinery replacement, and process changes. The second section of the questionnaire consisted of seven questions identifying the frequency with which investments of this nature were undertaken, the time period in which the actions were taken, and the relative importance in terms of energy saved. The specific projects in this category are listed below (the number of mills that undertook the measure is given in parenthesis)

- Upgrade steam line and process equipment insulation systems (9)
- Replace incandescent lighting fixtures with more efficient flourescent sodium or mercury vapor units. Use skylights and windows where possible (7)
- Reduce building heat loss during cold weather by improving insulation (1)
- Increase heat recovery from exhaust gaseous streams (8)
- Improve lubrication and bearing systems (2)

The coast mills completed proportionately more general housekeeping energy conservation projects. Two interior mills did not complete any projects of this nature. Six mills undertook projects between 1977 and 1980 (five coast mills), and eight mills completed projects between 1980 and 1984. Only one mill completed projects of this nature in the 1974-1976 period. All but one mill indicated general housekeeping measures accounted for less than 10% of the energy savings. The exception was a coast mill where general housekeeping measures accounted for between 25 and 50% of the energy saved.

The second category of energy conservation projects related to the installation of new fuel-efficient equipment or the replacement of existing equipment with more fuel-efficient units. The primary motive for the investment was immaterial for our purposes. The specific projects in this category are listed below (the number of mills that undertook the measure is given in parenthesis).

- Install computer control on batch digester system to reduce peak steam demands (6)
- Install new boiler controls, gas analyzers and other devices to improve boiler efficiency (11)
- Upgrade steam condensate recovery systems (7)
- Modify electric motor selection standards to ensure optimal efficiency (6).
- Modify use and selection practices of process equipment such as pumps, fans, etc., to ensure optimal operating efficiency (3)
- Upgrade and rehabilitate boiler feedwater

heating systems (7)

- Replace or upgrade heat exchanges (6)
- Install boiler blowdown heat recovery units (4)
- Other projects cited were:
  - install hog fuel drying system (2)
  - install hydro generator (1)
  - install computer control on paper machines (1)
  - install computer control on bleach plant and recovery boiler (1)
  - install back pressure turbine generator set (1)
  - replace mechanical steam fan drives with electric motors (1).

Proportionally, the coast mills undertook more projects of this nature than interior mills. For interior mills, upgrading the steam recovery systems, installing new boiler controls, and upgrading the boiler feedwater systems were the most frequently noted projects. New boiler controls were installed in nearly all coast mills. Installing computer control on the batch digester and modifying electric motor selection were also noted frequently. No projects of this nature were undertaken before 1977. In the 1977-1980 period, five coast mills implemented one or more of the projects, while most of the projects were implemented in the 1981-1984 period. The industry indicated that projects of this nature generally accounted for at least 25% of the energy savings realized. Interior mills' responses ranged from less than 10% to several mills indicating equipment changes accounted for more than 50% of the energy savings realized. Most of the coast mills indicated that equipment changes accounted from between 25 and 50% of the energy savings realized.

The final category of energy conservation activities was process changes that resulted in reduced energy consumption. Specific projects in this category are listed below (the number of mills that undertook the measure is given in parenthesis).

- Improve recovery of waste liquor for firing in chemical recovery units (11)
- Increase press loading on paper machine to reduce drying requirements (4)
- Recycle warm filtrates in bleach plant (8)
- Optimize fresh water consumption in bleaching, pulping and papermaking areas (10)
- Improve distribution of steam for mill heating units (2)
- Reclaim compressor cooling water (3)
- Close up paper machine white water systems (8)
- Use waste process hot water in woodrooms to reduce steam requirements (1)
- Other projects cited were:
  - use reclaimed hot water in bleach plant in lieu of heat exchange from steam (1)
  - reclaim motor cooling water (1)
  - operate refiners at a more constant load by installing a larger refiner stock storage tank (1).

Proportionally interior and coast mills implemented process-related energy conservation projects with equal frequency. Improving recovery of waste liquor and optimizing fresh water consumption were the two most frequently noted projects. Fifty percent of the responding mills also chose to close up the white water systems. Like the other energy conservation projects, most mills did not implement process related energy conservation projects before the 1980-1984 period. The mills rated these projects as relatively effective in reducing energy consumption. Only one mill indicated that process changes accounted for less than 10% of the total energy saved. The remaining mills estimated that process changes accounted for more than 25% of the energy saving realized. Interior mills more frequently credited process changes with the larger saving.

Earlier it was noted that the industry had pursued energy saving strategies along two fronts. In terms of effective projects, the industry clearly indicated that projects categorized as general housekeeping effected relatively small energy savings. Equipment replacement and process

changes resulted in relatively large energy savings. For interior mills, machinery replacement or process changes often accounted for greater than 50% of the energy savings realized. In there mills equipment replacement projects such as installing new boiler controls, upgrading steam recovery systems and upgrading boiler feedwater systems were particularly effective in reducing total energy consumption. Effective energy-reducing process changes included improving the recovery of waste liquor, recycling warm filtrates and closing up the white water systems. Coast mills generally implemented the same types of projects, but frequently indicated relative energy saving in the 25-50% range. This differential may partially explain the divergent trends in total energy consumption noted in the previous section. With regards to project implementation, about 70% of the energy conservation projects were undertaken in the 1981-1984 period.

Fuel substitution

The recovery boiler is the largest energy source in the typical kraft mill. It generally accounted for about 50% of the kraft mill's total energy requirement. The recovery boiler also reclaims process chemicals and reduces pollution. Half of the responding mills indicated that the recovery boilers had been upgraded or replaced since 1974. The frequency was the same for interior and coast mills. Most of the mills were unable to quantify the purchased fuel savings however. Of the mills reporting a value, the average improvement was 410 pounds of steam per hour per tonne of production. This is roughly equivalent to one-twelfth of a barrel of oil per tonne of production. This modest energy gain generally confirms the information provided in response to question one. Although the recovery boiler is the major energy source at most mills, it has not been an important avenue for reducing purchased fuel requirements since 1974.

The remaining questions examined the significance of biomass (referred to as hog fuel) as an energy source. All but one of the responding mills indicated that hog fuel was an important fuel source[3].

The generally higher hog fuel consumption in 1984 has resulted from the displacement of fossil fuel given 1974 production levels, and the added energy requirement given capacity expansions since 1974. In 1974, average hog fuel consumption ranged from a low of 1.6 GJ/tonne to 14.9 GJ/tonne of production[4]. The average value was 8.0 GJ/tonne. In 1978, the average value had increased to 9.6 GJ/tonne. By 1984, consumption ranged from a low of 4.3 GJ/tonne to 21.2 GJ/-tonne of production. The average value in 1984 was 10.9 GJ/tonne of production. Ten mills reported an increased use of hog fuel per tonne of production, with several mills reporting an increase of over 100%. Average hog fuel consumption per tonne of production remained roughly constant at the other mills.

The industry's increased use of hog fuel in the 1974-1978 period stands in contrast to the general lack of energy conservation projects during the same period as noted in the last section. The interior mills, in particular, increased hog fuel consumption during the 1974-1978 period. From 1974 to 1984, interior mills increased average hog fuel consumption 2.7 GJ/tonne of production over the 1974 average value. Nearly 90% of the increase had been realized by 1978. Coast mills increased average hog fuel use 3.0 GJ/tonne over the ten-year period. However, only 30% of the increase had been realized by 1978. In terms of fossil fuel equivalents and adjusting for different combustion efficiencies, the interior industry displaced the equivalent of 2.7 mcf per tonne of production in 1984 relative to 1974 values. The coast displaced an equivalent of 0.5 barrels of heavy fuel oil[5].

Beginning in 1978 the federal FIRE program offered financial assistance to mills undertaking qualified capital projects that displaced fossil fuels. Roughly 40% of the industry indicated a FIRE grant was received to help finance the hog fuel conversion/expansion projects. The frequency of occurrence was the same for interior and coast mills. Almost two-thirds of the mills indicated they were consuming the maximum volume of hog fuel in 1984. Nearly all of these

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[3] As noted earlier, one mill does not require a steam plant.

[4] There is not a common industry standard for measuring hog fuel. In this report hog fuel was first expressed in cubic metres of solid wood then converted to an energy equivalent value. See the Appendix for the conversion factor used.

[5] This assumes fuel efficiency factors of 85% for fossil fuels and 65% for hog fuel. The energy conversion factors used throughout the report are presented the Appendix.

mills also indicated the intent to invest in additional hog fuel burning capacity sometime over the next five years. The most frequently cited intentions were to use hog fuel in the lime kiln and/or to add a hog press, or both. The fossil fuel saving from the additional investments averaged about 2 GJ/tonne of production.

Approximately one-third of the responding mills indicated that hog fuel consumption was constrained in 1984. The constraints cited were: that the hog fuel was occasionally too wet; foreign material in the hog fuel; fly ash removal problems; limited by capacity of the hog fuel handling system; and boiler operational problems. The mills indicating a hog fuel constraint also intend to overcome the respective constraint. The following potential constraints were not cited by any mill:

- insufficient supply
- too expensive
- insufficient on-site storage.

The industry's responses indicated that the substitution of hog fuel played a dominate role in reducing the dependence on fossil fuels. Furthermore, the majority of mills intend to increase or improve the utilization of hog fuel over the next five years.

Another avenue for reducing purchased fuel costs is the substitution of self-generated electricity for purchased power. In 1974, 60% of the responding mills utilized self-generated electricity. The contribution of self-generated power to total electricity requirements varied among mills. Of the mills having generating capacity, one coast mill was entirely self-sufficient while another met as little as 25% of its electricity requirements internally. Most of the mills with generation capacity satisfied over half their electricity requirements internally. By 1984, three additional mills had added self-generating capability. Still only one mill was entirely self-sufficient while two other mills generated almost 90% of their electricity requirements per tonne of production. However, the trend in total industry production has been to greater electric energy input per tonne of product. In 1974, the industry's average electricity requirement per tonne of product was 980 Kwh. In 1984, the industry's average electricity requirement was 1105 Kwh. For those mills with generating capacity, average self-generated electricity was 589 Kwh/tonne in 1974 and 616 Kwh/tonne in 1984. That is, while the average electricity input increased some 13% over the period, the input from self generated sources increased only about 4.5%. While self-generated electricity constitutes an important source of energy for particular mills as well as for the industry, it does not appear to have accounted for a significant reduction in fossil fuel use over the period 1974-1984.

Ranking of energy conservation and fuel substitution measures

First, the mill was asked to rank the projects in terms of the volume of fossil fuel displaced. A "1" would be placed by the measure that displaced the greatest volume, a "2" beside the next most effective project, and so on with a "6" placed beside the least effective project. It should be noted that the system of priorizing measures indicates the relative ranking for a particular mill, but cannot be used to rank projects among mills; the most effective project at one mill may rank lower at another where, in total, a greater volume of fossil fuel was displaced. On the other hand, the ranking system clearly indicates the industry's diverse response in terms of tailoring the need to reduce fossil fuel consumption to the mill's particular circumstances. The mills' ranking of projects is summarized in Table 3.

The measure that accounted for the greatest displacement of fossil fuels varied among the mills. At several mills the switch to self-generated electricity accounted for the greatest fossil fuel savings while at other mills modifications to the recovery boiler accounted for the greatest fossil fuel savings. Process changes, equipment replacement and the increased use of hog fuel, were cited with equal frequency and, in sum, were the most effective projects at 75% of the mills. No mill ranked general housekeeping as the most effective measure.

Referring to question five, we find that those mills citing machinery replacement as the most effective measure had undertaken a relatively large number of projects. Those most often cited were installation of computer control on the digester and installation of controls to improve boiler efficiency. For those mills citing process changes as the most effective measure, the most

Table 3. Ranking of energy savings measures by volume of fossil fuel displaced

	Rank						No response
	1	2	3	4	5	6	
	%						
General housekeeping	0	6	13	19	19	38	6
Equipment replacement	25	31	19	19	0	0	6
Process changes	25	6	31	19	13	0	6
Increased production from the recovery boiler	13	6	6	25	25	6	19
Switching to hog fuel	25	44	13	0	6	0	13
Switching to self-generated electricity	13	6	13	0	19	19	31
No response	0	0	6	19	19	38	19

(Note: Columns and rows may not sum to 100% due to rounding)

frequently cited projects were the improvment of recovery of waste liquor, recycling warm filtrates and closing up the white water system.

The mills were less divided in selecting the second most effective measure. Nearly one half cited switching to hog fuel. There was also general agreement that housekeeping measures displaced relatively small volumes of fossil fuel in most mills.

The mills were also requested to rank the six categories of measures in terms of financial criteria (Table 4). A "1" would indicate the project that resulted in the greatest internal rate of return, shortest payback period, etc. Given the decline in fossil fuel prices over the past several years from those forecast in the 1970s, this question attempts to identify the investments that had not achieved the cost savings expected. Many of the investments the survey considered as primarily energy-related also reduced material requirements or improved production efficiency. Hence the financial ranking of the projects may have taken into account cost savings realized from other aspects of mill operations.

The ranking of measures according to financial criteria diverged somewhat from the ranking based on fuel displaced. Switching to hog fuel resulted in the highest financial return for the greatest number of responding mills, or 38%. Several mills that had ranked the switch to hog fuel second on an energy displacement basis, ranked it first on a financial basis. On the other hand, two interior mills that had ranked switching to hog fuel first and second on an energy displacement basis ranked it third and fourth on a financial basis, respectively. With respect to machinery replacement and process changes, all of the mills that had ranked the measures first on the energy displacement criteria did so on a financial basis as well.

The final question asked how the ranking of energy conservation and fuel switching investments might change relative to competing investment opportunities over the next several years. The respondents indicated whether the energy-related investment would become more attractive, less attractive, or remain about the same. Over 40% of the responding mills indicated that energy-related investments would become more

Table 4. Ranking of energy saving measures by financial criteria

	Rank						No response
	1	2	3	4	5	6	
	%						
General housekeeping	6	0	13	19	19	38	6
Equipment replacement	19	31	25	13	6	0	6
Process changes	25	13	38	19	0	0	6
Increased production from the recovery boiler	6	19	6	19	25	6	19
Switching to hog fuel	38	25	13	6	6	0	13
Switching to self-generated electricity	6	13	0	13	25	19	25
No response	0	0	6	13	19	38	25

(Note: Columns and rows may not sum to 100% due to rounding)

attractive than competing investments. Fifty percent indicated the ranking would remain about the same, and only one interior mill indicated that energy projects would become less attractive.

There was a marked difference between interior and coast mills in response to this question. The interior mills indicated that the ranking of energy-related investments would either remain about the same or decline relative to competing investments. The majority of coast mills indicated that energy related investments would become more attractive while the remaining mills indicated it would remain about the same.

Summary and conclusions

In the future, one might expect the industry's effort to reduce energy consumption to diminish, given that fossil fuel prices are projected to remain relatively stable over the medium term (Robinson 1984) and given the improvement already realized. This does not appear to be the case, however. Although energy costs are expected to remain stable they still constitute a large proportion of total production costs. Nearly all of the responding mills indicated that energy saving investments would remain attractive, or become more attractive over the next several years. Indeed, several mills indicated in conversation the expectation of significant fossil fuel reductions in 1985 with the completion of several major projects.

The industry continues to respond to higher energy prices. We expect to see a further reduction of fossil fuel requirements as the mills implement additional energy conservation and fuel substituting measures. The increased use of hog fuel has played a key role in nearly every mill's energy strategy in terms of displacing a large volume of fossil fuel and providing a reasonable financial return. The mills indicated that hog fuel use would continue to play an important role in their on-going effort to reduce fossil fuel consumption.

References

Hohol, R. 1982. Industry making progress, but tough decisions ahead. Pulp and Paper Journal, March 1982, pages 14-15.

Robinson, G. 1984. Impact of heavy fuel oil and natural gas prices on the value of biomass delivered to British Columbia pulp mills. Can. For. Serv. Pac. For. Res. Cent. Inf. Rep. BC-X-256.

Appendix — Conversion factors

A) Volume and weight

1 tonne (metric ton) = 100 kilograms
= 2204 pounds

1 barrel = 42 American gallons
34.9726 Imperial gallons
.15898 cubic metres

B) Heavy fuel oil conversion factors

1 Barrel = 34.9726 Imperial gallons
= 6.63 GJ
= 6.290 MMBTU
= .1515 tonne (or approximately 6.6 barrels per tonne)

C) Natural gas

1 mcf = one thousand cubic feet
1 mcf = 1040 MMBTU
= 1.0968 GJ
= .0283 cubic metre
or one cubic metre = 35.3 cubic feet
= 10 400 therms

D) Hog fuel

Coast

1 volumetric unit = 200 cubic feet
= 5.67 cubic metres
= 2.068 solid wood equivalents (Coast)
= 1.53 green tonne

Interior

1 bone dry unit (BDU) = Whitewoods 2.674 m^3 solid wood (H/B/S/P1)
= Fir/larch 2.551 m^3 solid wood
= Cedar 3.390 m^3 solid wood

1 m^3 solid wood = 8.078 GJ